# ENVIRONMENTAL PROTECTION AND THE CORNELL UNIVERSITY NUTRIENT MANAGEMENT PLANNING SYSTEM: FUTURE PERSPECTIVES

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## EMERGING PRIORITIES FOR NUTRIENT MANAGEMENT

During the last decade, livestock feeding operations were identified as major non point sources of water and air pollution. Since the first EPA-USDA guidelines were released in 1999 to address this problem, the focus has been to develop and implement comprehensive nutrient management plans (CNMP) on livestock operations between 300 and 1000 animal units (au) with the potential to discharge, or greater than 1,000 au (US EPA, 1999). The guidelines are currently being reviewed with an updated version scheduled to be released in December 2002. Although the exact direction of the new guidelines will not be known until the release, the following are under discussion: maintaining the current three-tiered definition of a concentrated animal feeding operation (CAFO) or changing to a two-tier definition (greater than 500 au considered a CAFO); requiring all CAFO to determine whether a hydrologic link exists between the production facilities and water sources (ground and/or surface); eliminating the 25 year, 24 hour storm discharge allowance for veal, poultry, and swine (can dairy and beef be far behind?); and requiring the application of nutrients to croplands be in accordance with the Natural Resource Conservation Service (NRCS) 590 Nutrient Management Planning Standard (US EPA, 2002). The NRCS has the responsibility for implementing Federal Guidelines. NRCS has been focused on developing and implementing standards to control farmstead runoff and nutrient (nitrogen (N) and phosphorus (P)) leakage into surface and ground water from fields by using soil testing, Land Grant University guidelines for crop nutrient requirements and risk indices for N and P for manure and fertilizer application rates, timings, and methods. Allowing manure ammonia to volatilize has not been a concern, and has been viewed by most as an accepted method to reduce N volume on farms thus reducing risk of excess N leakage to water sources. Likewise, little attention was given to the major source of excess nutrients for dairy and beef operations in the United States; imported feed.

Recent conferences and discussions indicate that the following will be addressed in future regulations and guidelines to reduce risk to water and air quality:

1. Nitrogen losses through volatilization are becoming an issue, and regulations are likely to be forthcoming,
2. The concerns relative to phosphorus are shifting to finding ways to evaluate the impact on Total Maximum Daily Loads (TMDL) in impaired water bodies, and
3. NRCS is beginning to address Feed Management as a way to reduce excess nutrients on livestock farms.

## NITROGEN LOSSES TO THE ENVIRONMENT

Until recently, regulations have focused on controlling N losses to ground water to control the risk of nitrate toxicity from drinking water in infants less than 6 months old, and in coastal surface water to control the impact of excess N on aquatic plant life, particularly algae blooms. Concerns about ammonia losses to the atmosphere are now being raised with the proposed shift in particulate matter size that can be regulated (proposed reduction of 10 to 2.5 microns) in addition to water quality concerns. The Northeast, particularly Central and Western NY, has areas with the highest concentrations of inorganic N wet deposition from nitrate and ammonium in the United States (National Atmospheric Deposition Program, 2001). Current estimates suggest atmospheric N deposition can contribute 10-40% of new N enrichment of coastal and estuarine waters (Paerl, 1997). Ammonia is often a preferred N form for biological activity in water and its increasing availability can cause fundamental changes in aquatic algae communities. Additionally, ammonia contributes to the formation of fine particulate matter (ammonium nitrate and ammonium sulfate) in the atmosphere and can affect human health including premature mortality, chronic bronchitis, and asthma attacks (McCubbin et al., 2002). The dominate source of US ammonia emissions is agriculture with about 70% stemming from livestock operations and the majority of the remainder resulting from post-nitrogen fertilization losses and motor vehicle emissions (McCubbin et al., 2002). Nitrous oxide, a potent greenhouse gas, is of concern as well. Its agricultural source is as variable proportions of animal N excretion and N fertilizer applied to crop land (Johnson et al., 2002). Therefore, we can expect to see increased emphasis in nutrient management planning on reducing nitrogen losses to the atmosphere from livestock operations. Hutson et al. (1998) found that large amounts of N were volatilized on a dairy farm, and occurred at many points between excretion and land application.

The European Union has been developing and implementing N policy since 1991 (Henkins and Van Keulen, 2001). The EU Nitrate Directive obliges EU member states to reduce the nitrate loading from agriculture to surface and ground water. Once acceptable levels are reached, controls must be in place to limit further pollution. The target nitrate level the EU is using is 50 mg/l Nitrate (similar to our 10 mg/l Nitrate-N). The agricultural objective is to balance the use of manure and chemical fertilizer with crop requirements. Unlike our dairy industry, countries such as England and the Netherlands have relied on very high nitrogen applications to maximize grass yield and quality (we have been told of rates as high as 450 lbs N/a). The EU directive thus far has been focused on decreasing N loading in the cropping system (with a 170 to 250 lb/a range being discussed). Their approach to regulation is slightly different in that they are regulated based on farm-gate nutrient balances that include acceptable environmental emissions. Failure to meet farm-gate balances results in fines with the current P fine being approximately $9 per kg in excess and N resulting in $2.25 per kg in excess. Nitrogen and phosphorus imports are closely tracked, and in the Netherlands, feed and fertilizer companies are required to submit all invoices including N and P content to the regulating agency. Fines are determined annually and added to the farm's income tax charges with many of the on-farm calculations being done by financial accountants. The decision as to how a farm meets the regulations (the within farm nutrient flow) is flexible as long as best management practices are followed to limit N losses to the environment. The Dutch are beginning to look at how animal production and diets impact excretion. They are hopeful that through diet manipulation, they can decrease ammonia emissions; however given that most of their diets are grass silage/pasture based and they must import most of their carbohydrate sources, accomplishing this will be difficult. Other areas they are pursuing include animal number reductions, exporting manure, and maximizing herd management and production per cow. Herd management and cow production are meant to improve the farm-level N efficiency. They are attempting to minimize cull rates to minimize the size of the replacement herd as growth is much less N efficient compared with milk production. Additionally, milk production exports N off the farm whereas growth remains on the farm; thus, growing animals negatively impact their farm-gate N balance.

## PHOSPHORUS LOSSES TO THE ENVIRONMENT

Phosphorus losses from agriculture are considered to significantly contribute to the eutrophication of freshwater ecosystems (Sharpley, 2000a). In turn, eutrophication can result in reduced levels of dissolved oxygen, fish kills, the evolution of carcinogenic byproducts (e.g. trihalomethanes, haloacetic acids) during the chlorination of drinking water, and diminished recreation value of watercourses (Palmstrom et al., 1988; Sharpley, 2000b; US EPA, 1998). Therefore, agriculture will continue to be under pressure to improve phosphorus management.

## THE TMDL APPROACH TO NUTRIENT MANAGEMENT

The federal Clean Water Act of 1972 (CWA) requires states to identify, prioritize and report to the US EPA waters whose quality is threatened or impaired by point and non point source pollution. The CWA states that point sources must be controlled first and in cases where water quality goals cannot be met by post-point-source intervention, states must develop and implement Total Maximum Daily Loads (TMDL) for the water body (US EPA, 1991). A TMDL provides guidelines regarding how much of a given pollutant is allowed to enter ("load") a water body to achieve (or maintain) a water quality goal and are the sum of point and non point sources (US EPA, 1991). TMDL development for a given watershed requires "load allocations" be quantified for each point and non point source (US EPA, 1991). From a watershed perspective this can be viewed as "backing" the pollutant load up the watershed and assigning an allowable amount to its various sources (including agriculture). Communities seeking to manage watersheds to meet TMDL must consider all sources of a given pollutant, and then prioritize watershed management based on the relative proportions of source loads and cost/benefit analysis of source management controls. In essence, this requires nutrient management planning to occur at the community, sub-basin, basin, and farm level.

The CNMP of farms in watersheds with TMDL constraints will need to begin quantifying and documenting impacts that implemented best management practices

(BMP) have on the farm nutrient fluxes. Qualitative assessments of BMP impacts will no longer be adequate as communities striving to meet TMDL will need to quantify load reductions from the implementation of BMP on a given farm, and then aggregate individual farm reductions across the watershed, calculating a total reduction from agricultural non point sources. The use of computerized models like the Cornell University Nutrient Management Planning System (CuNMPS) will be essential in accomplishing this. As each farm is subject to unique variation in landscape and management, using computerized models allows for developing “site specific” recommendations and impact predictions for implemented BMP. This requires the use of the best science available and highlights the need for continuous development and refinement of the CuNMPS. Site specific plans, and utilizing the best science, are especially powerful when actual monitoring data is difficult to obtain and when watershed resources are limited. In predicting BMP impacts (both individual BMP and collections of BMP) and aggregating across spatial and temporal planes with the ultimate goal of predicting pollutant load reductions on a farm and across a watershed over time, computerized models will be essential, and it will be required that these models can share data between them allowing for watershed analysis.

## FEED MANAGEMENT TO REDUCE N AND P LOSSES TO THE ENVIRONMENT

The NRCS has the responsibility of providing technical assistance for implementing USDA policy relative to farm bill conservation title programs, including the development of CNMP to protect water quality. Their current goal has been to develop CNMP that match manure application rates with agronomic requirements. Recently, USDA-NRCS has identified the need to improve feed management to reduce manure nutrients. This would reduce the acres required to efficiently utilize manure and reduce environmental losses (Tom Christensen, NRCS director for animal husbandry and water quality, personal communication). This shift in focus is consistent with our data that indicates that two thirds to three fourths of the excess nutrients on dairy and beef farms originate as purchased feed (Fox et al., 2002). The NRCS does not intend to address feed management with their field staff; their approach is to provide them with general guidelines that can be used to make field staff aware of the impact appropriate feed management has on reducing manure nutrients, and to encourage producers to use professional nutritionists to address feed management.

We view effective feed management planning (with the objectives of reducing: 1) nutrient loading, 2) spreadable acres needed, and 3) nutrient losses) as having three components;

- Precision diet formulation to reduce feed required and manure nutrients,
- Improving feed storage (minimize wasted/loss inventory) and feeding management, and
- Improved formulation to more closely match herd requirements with more homegrown feeds from the cropping enterprise, thereby reducing imported nutrients.

Our studies have shown that implementing whole farm plans that integrate nutrient management across herd, crops, soils and manure components can reduce nutrient concentrations on dairy farms while increasing economic returns (Albrecht et al., 2002; Cerosaletti et al., 2002; Fox et al., 2002; Tylutki and Fox, 2000; Tylutki et al., 2002; Wang et al., 2000b). Based on data collected, and observations made in these studies, we developed priorities for management that can be used to minimize nutrient losses in the ***short-*** (can be implemented within days or weeks) and ***longer-term*** (requiring one or more crop years, or significant management shifts to implement).

Implementation of these feed management changes must be done so that milk production, growth, reproduction, and animal health are not compromised. These methods revolve around two areas: 1) decreasing nutrients brought on the farm by more accurately formulating rations based on farm specific animal requirements and feed content of carbohydrate and protein fractions and P, and 2) improving the efficiency of nutrient utilization through improved feed and crop management strategies that aim to increase nutrient recycling within the farm boundary. Our data and observations indicate the following feed management practices should be routinely implemented on dairy farms in the future.

Short-Term Strategies

1. *Formulate farm and group specific rations****.*** The studies of Tylutki and Fox (2000) and Tylutki (2002) demonstrated the impact of inaccurate ration formulation and quality control on variation in milk production and income. Based on these and other studies, we believe models such as the Cornell Net Carbohydrate and Protein System (CNCPS) will be utilized in the future to accurately predict farm specific animal nutrient requirements, absorbed nutrients from each feedstuff available to meet requirements, and nutrient excretion that can be used for manure nutrient management planning. Of particular importance are models that result in optimizing the rumen to maximize forage utilization and microbial protein production. Data and feed analysis required by models must be farm specific (housed on-farm) and accurate.
2. *Appropriate feed analysis schedule and protocol to accurately represent the feeds being fed*. To accomplish this, a farm specific feed analysis protocol needs to be followed resulting in a farm specific feed database that includes forages and concentrates. Tylutki et al. (2000) simulated the impact of NDF and dry matter variation in corn silage using the average values and standard deviations as sampled on a 500-cow farm. The impact of improper forage analysis, and lack of control over the dry matters at feeding, resulted in a large annual variation in nutrient excretion (242 pounds N excretion and 64 pounds of P excretion), feed inventory required (61 tons of corn silage), and income over feed costs ($21,792) per 100 cows annually. Their recommendations include determining dry matters of all forages at least twice weekly (more often if wide fluctuations in intakes are observed) and then adjust diet formulations as needed.
3. *Improve feeding accuracy*. Most farms assume that what is being mixed and fed is what is supposed to be fed. In many cases, this is not a valid assumption

(Predgen and Chase, 2002). Tylutki et al. (2000) evaluated the impact of varying feeding accuracy ± 3%. The addition of feeding error increased annual variation in P excretion (18 pounds), corn silage inventory (9 tons), and income over feed costs ($19,148) per 100 cows annually. Feeding accuracy needs to be tracked to identify sources of variation, as well as to manage inventory. Commercial software and hardware are available that can be linked to the mixer scales to track this information.

4. *Monitor dry matter intake to improve accuracy of ration formulation and animal performance*. Proper ration formulation relies on many inputs from the farm, including animal body weight, feed inventory, and actual dry matter intakes. To decrease nutrient excretion per unit of milk produced, actual dry matter intakes must be known in order to ensure adequate grams of each nutrient are provided to support animal requirements. The data can also be used as a diagnostic tool.
5. *Make ration changes as needed to improve accuracy and minimize safety factor in the ration.* By increasing the dry matter intake 5%, ration nutrient concentrations can be lowered. Chase (1999) calculated that by increasing intake 5%, it is possible to decrease diet crude protein about one percentage unit to achieve the same pounds of protein intake. This allows higher inclusion rates of homegrown feeds, thus decreasing purchased nutrients. Safety factor reduction, while very effective in reducing excretion, requires a high management level, thus management and feeders need additional training to minimize potential performance variation (Tylutki, 2002).
6. *Improve feed-bunk management to increase intake and consistency of animal performance*. This includes daily cleaning, pushing feed up several times daily, and all other bunk management practices. More consistent performance, and feed intake, allows for more accurate ration formulation for any production level.
7. *Control the level of refusals*. Most farms' feed refusals from the lactating herd are fed to replacement heifers. From a nutrient excretion viewpoint, this is an expensive practice. Mineral and protein levels that are adequate for lactating cows do not fit most replacement heifer groups. The amount of refusals must be at a level that is consistent with farm management to achieve maximum dry matter intake; however extremely high levels need to be avoided and are indicative of poor management.
8. *Use the proper 'tools' to track the impact of changes in ration formulation and feeding management*. These 'tools' fall into two categories: short-term (milk production, milk components, and milk urea nitrogen) and long-term (body condition score, replacement heifer growth, lactation persistency, and reproduction). Both sets of tools are required to accurately evaluate a herd.
9. *Obtain and evaluate manure analysis*. Manure needs to be analyzed two ways: visual observation to determine what is not being digested by the cow, and the second is a manure nutrient analysis at time of land application. If large fiber particles or corn grain is evident in visual observation, rations and feeding management need to be addressed. As dietary N and P levels are decreased, manure nutrient concentrations will be decreased.

## Long-Term Strategies

1. *Develop a crop and manure nutrient management plan.* Cornell Cropware software can be used in New York State to meet CAFO requirements while matching manure and commercial fertilizer nutrients with crop requirements to produce crop yields up to soil potential (and management level) on each farm.
2. *Improve silo management*. Silo capacity and management can play a significant role in decreasing nutrient excretion. Most dairy farms have varying soil types that are best suited for different crops from a crop production and environmental management standpoint. The storage system must be able to handle each crop type individually (e.g., corn silage, grass silage, alfalfa silage, and different qualities of each). This allows the nutritionist to better match protein and carbohydrate sources with specific animal groups.
3. *Manage forage inventory to avoid feed shortages*. Proper ration planning, and inventory management, decrease farm nutrient loading. This is because a forage deficiency requires additional purchased feed and automatically increases purchased feed excretion. The CNCPS predicts requirements for each ration ingredient (by group and the entire herd), and can be used to allocate, and manage, forage inventory.
4. *Match cows/crops/soils*. Alfalfa and corn are not always the best choices for dairy producers due to soil constraints. The farm's manager(s), nutritionist, and field crops consultant must work together to determine the best mix of crops to grow, and how they can be fed, allowing for production goals (crop and animal) to be met while minimizing nutrient excretion. Future CuNMPS versions will predict feed production with alternative crop rotations, and management, to minimize farm-gate imported nutrients and the spreadable acres required.
5. *Increase the amount of homegrown feeds in the ration*. Increasing the amount of homegrown feeds in the ration decreases the amount of purchased nutrients. To accomplish this, homegrown feeds must be high quality to maintain (or improve) production and animal health, and stemming from optimal rumen fermentation.
    a. *Impact of Forage quality*. To increase the amount of forages in the rations, forage quality must be high. Maximum intake from forages can be expected when alfalfa is <40% NDF, grasses are <55%, and corn silage is 40-45% (Tylutki and Fox, 2000). A cow is limited in forage NDF intake to 1 to 1.1% of bodyweight (Mertens, 1994). As an example, a 1400 pound cow at 1.1% NDF capacity can consume 28 pounds of dry matter from grass at 55% NDF but only 24 pounds at 65% NDF. This four pound difference results in either increased purchased feeds and/or lower performance. In either case, purchased nutrient efficiency is lower.
    b. *Impact of Grains*. Homegrown grains and protein sources decrease the amount of purchased nutrients. Many dairy farms do not have an adequate land base to produce their own grain; therefore, they should maximize forage quality and choose purchased concentrates that accurately supplement their forages.

## REFINEMENTS OF THE CuNMPS TO IMPROVE ITS USEFULNESS IN FEED MANAGEMENT

The development of whole farm plans to improve nutrient and feed management is complex, and requires the integration of a large amount of research and knowledge (Klausner et al., 1998). We developed the CNCPS (Fox et al., 2000) and Cornell Cropware (Rasmussen et al., 2002) to facilitate the on-farm application and development of site-specific plans arising from accumulated knowledge and complex equations. These systems more accurately account for animal and crop requirements, and manure and soil management, all components of CNMP. The objectives of future CuNMPS development relating to improving feed management are two fold: continued enhancements in the biological systems modeled by CNCPS and Cropware, and enhancements to improve their field usability. These improvements include developing quantifiable relationships from an ever – increasing understanding of the biological, chemical, and physical responses of animals, crops, soils, and landscapes via research and incorporating this knowledge into decision support systems (DSS) using the latest modeling techniques, resulting in a user-friendly suite of DSS.

1. *Refinement of the biology in the CNCPS model*. The CNCPS model is available by sending an email to *mlc44@cornell.edu.* In on farm tests and research evaluations, it has proven useful in improving animal performance while reducing N and P excretion and costs (Fox et al., 2002). The next version is under development with goals of improving its accuracy in formulating diets, including energy, protein (N), and feed optimization and allocation of homegrown forages across groups in a herd, and accuracy in prediction of N and P excretion.

Because of ruminal pH effects on fiber digestibility and microbial protein production and therefore homegrown forage utilization, we are developing a dynamic ruminal sub-model to account for the effects of ruminal VFA production, absorption, and fluid dilution rate on ruminal pH. It is well documented that factors other than fiber particle size may have a more systematic and predictive role in determining ruminal pH. Such factors include starch processing (Yang et al., 2001), water intake, and saliva flow that dictate the amount of ruminal VFA that is washed out of the rumen (Allen, 1997). Meng et al. (1999) demonstrated that increasing the dilution rate from 2.5 to 20% per h resulted in an increase in ruminal pH from 5.78 to 6.91. Russell (1999) suggested that when cattle are fed a large amount of grain, ruminal carbohydrate digestion, VFA production, and consequently ruminal VFA concentrations are much higher, but the fluid dilution rate is relatively slower than animals fed high forage diets. Under these conditions, a high proportion of the VFA produced in the rumen has to be absorbed there. Therefore, the VFA content in the rumen and fluid dilution rate control the ruminal pH. Several variables must be accounted for in developing this dynamic model. The feeding behavior (feeding frequency, i.e. 1x, 2x, 3x per d; time spent chewing and ruminating, oscillation of eating pattern), has a large impact on the amount, type, and the time that carbohydrate is available for the ruminal bacteria (Dado and Allen, 1994). Accurate and consistent measurements of degradation rates have an effect on amount of carbohydrate predicted to be degraded in the rumen; there are differences between degradation rates derived using different nonlinear functions (Fitzhugh, 1976). The fluid dilution rate (or liquid passage rate) has to be as accurate as possible in order to estimate the amount of VFA washed out of the rumen. The dynamics of VFA absorption in the rumen must be accounted for to ensure that models can predict the amount of available VFA for animal production of meat or milk (Dijkstra et al., 1993). The water intake (influx in the rumen) is also a part of the VFA absorption dynamics since it affects the rumen viscosity and therefore the free movement of VFA within the rumen (Russell, 1999). A VFA sub-model will allow us to more accurately predict the energy derived from a diet and maximize fiber digestibility. This is very important as we move towards higher forage (homegrown) diets to decrease nutrient importation. The combination of eating behavior and more accurately accounting for starch processing will allow us to better match carbohydrate and protein pools in the rumen and the animal.

Because of the need to accurately predict the route (fecal or urinary) and form (e.g. potentially volatile ammonia) of N excretion, we are developing a new N model for the CNCPS (Figure 1). Currently, the CNCPS predicts total N excretion at acceptable levels; however, route of excretion has systematic bias with urinary N routinely underpredicted. Several approaches have been used to compute metabolic fecal N (MFN), but the most common is the regression of apparently digested N on N intake in which the slope indicates the true digestibility of N and the intercept indicates the MFN. Current and past versions of the NRC and CNCPS have relied on the value obtained by Swanson (1977) but the data set employed had severe shortcomings requiring a re-evaluation of the data. In addition, modern feeding conditions require feeding large quantities of grain, which in part are fermented in the hindgut, increasing the fecal excretion of N as bacterial N. We foresee that a mechanistic hindgut submodel will be required to accurately predict the fermentative processes occurring in the large intestine, including the production and absorption of VFA, the capture of N by hindgut bacteria, the recycling of urea to and the absorption of ammonia from the lower tract. Urinary N will be calculated by difference between N intake and the sum of N accretion, milk N, N retained as conceptus, surf N and fecal N. Endogenous urinary N (EUN) will be also computed to estimate N required for maintenance (J. Marini, personal communication).

Because of their contribution to Greenhouse Gasses, we intend to develop (and implement in the CNCPS) equations to predict methane ($CH_4$) and nitrous oxide ($N_2O$) production by cattle. In the rumen, hydrogen is produced during the anaerobic fermentation of glucose. This hydrogen can be used during the synthesis of volatile fatty acids (VFA) and microbial organic matter, the preferred pathways environmentally-speaking. The excess of hydrogen from NADH is eliminated primarily by the formation of methane by methanogenic bacteria, a non-preferred pathway. The stoichiometric balance of VFA, $CO_2$, and $CH_4$ (Wolin, 1960) indicates that acetate and butyrate promote methane production whereas propionate formation can compete with methane production. The development of a dynamic VFA-pH submodel and the revised N model will allow us to select better ration ingredients and feeding strategies to minimize $CH_4$

production and improve N utilization to minimize N excretion.

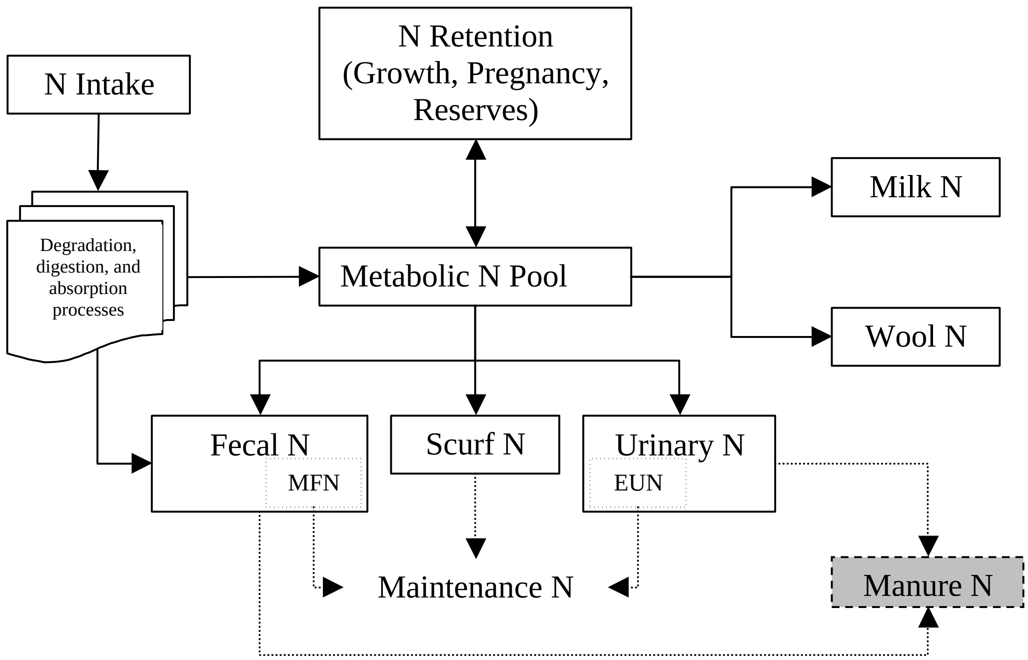


Figure 1. A revised N submodel for the CNCPS model

2. *Refinement of the CNCPS input structure*. The goal is to reduce the inputs needed to use the CNCPS while maintaining or improving its accuracy.

Several problems have been identified that restrict the use of DSS models, including their complexity and the number of inputs and information needed to execute DSS models (McCown, 2002). Data requirements for the CNCPS are already high, and future versions of the CNCPS will require additional inputs. These inputs are needed to more accurately determine carbohydrate and protein fraction digestibility in order to improve prediction accuracy of ruminal and post-ruminal N accounting (including rumen and whole tract recycled N), and absorbed amino acids derived from dietary and microbial sources. However, to offset the challenges of high data requirements and entry, we are developing input structures that can be used to streamline inputs (including feed analysis, animal inputs, and environmental inputs).

Despite limitations in utilizing DSS at the farm level, there is still optimism about its future because computational modeling is used in everyday life and provides a cost-effective (and attractive) way to describe and predict biological relationships (Newman et al., 2000). Furthermore, environmental regulations demand that producers make more accurate decisions regarding their production systems prior to implementing changes. Therefore, there is opportunity for use of DSS on farms, but care must be taken to build DSS that are user friendly, easy to understand, useful on the farm (how well it enhances decision-making), and are based on sound science.

3. *Refinement of Cropware.* The objective is to improve spatial and temporal planning of crop, soil, manure, and fertilizer nutrient management. This will allow for reductions in nutrient losses while increasing nutrient recycling and requires Cropware to be a connected component of the whole farm system.

The Cropware model is available from the Nutrient Management Spear Program (http://www.css.cornell.edu/nmsp) in the Department of Crop and Soil Sciences (CSS) at Cornell University (Rasmussen et al., 2002). It is a compilation of decades of crop and soil research performed by CSS resulting in a field useable tool for farm-specific nutrient management planning. Researchers from CSS and other institutions are continuing to refine guidelines for: soil specific nutrient requirements; perennial and annual forage production and management; site-specific forage species selection and management; nutrient availability from manures and composts; optimization schemes for allocating manure and fertilizer nutrients; and nutrient runoff and leaching risk indices (and models). These, and other research areas, are being conducted to maximize yield and quality while minimizing nutrient losses. Cropware will continue to serve as a delivery mechanism of the latest research for application in the field.

Future versions of Cropware will further assist nutrient management planners and farm managers in organizing CNMP inputs and outputs to streamline the planning process within the cropping system, and between systems on farms. Enhancements include links with: 1) soil analysis laboratories for direct downloading of soil test information, 2) whole farm record keeping systems, 3) software on handheld devices, yield monitors, and other electronic media, and 4) other decision support systems (for example: CNCPS, NRCS Customer Service Toolkit, geographic information systems, the Whole Farm Forage System Analysis Crop Rotation Module, and economic analysis software (Ekblad et al., 1999; Fox et al., 2000; Kilcer, 2002)). Linkages with other DSS and record keeping systems would enable farm managers and their advisors to evaluate the compatibility of existing and/or proposed plans among systems. As farm systems are tightly integrated, changes in crop rotations, crop and manure management, storage management, feed inventories, herd feeding approaches, herd management, and manure nutrient utilization can have unforeseen consequences across systems. Accounting for this integration requires an integrated planning tool.

4. CuNMPS *Model Integration*. The objective is the development of a programming structure that allows users to transfer and integrate components of the CuNMPS.

We believe the value of Cropware and CNCPS can be greatly enhanced when used in concert (CuNMPS) by a multidisciplinary team to support decisions spanning the basic dairy farm systems: crops, feeding, milking, replacements, and manure. The teams must be comprised of farm management and off-farm advisors. The tools can be used independently; for example, Cropware enables users to create plans that reduce nutrient losses and fertilizer costs. This is accomplished by determining opportunities to minimize insurance fertilizer use and maximize crop utilization of manure nutrients thereby recycling manure nutrients back to the feed pool. However, such improvements in nutrient utilization and recycling can be lost if, for example, the feed storage system is not managed to conserve harvested feed nutrients or the herd management is limiting animal utilization of the homegrown feeds. Failure to develop and implement plans in an integrated manner results in several potential flaws including a non-optimized system, and ripples introduced with unforeseen consequences in other systems. This can lead to decreases in farm efficiency, profitability, and increase nutrient emissions resulting in a non-sustainable business. Integration overcomes this as such plans consider the farm as a system of linked, interdependent enterprises and can lead to fewer losses and greater returns (Fox et al., 2002).

By programming linkages among software tools, future versions of the CuNMPS would improve the efficiency by which users could evaluate options (for example, a range of crop rotations, diets, herd groupings, or expansion options) and their impact on a series of desired objectives. The desired objectives must represent a new paradigm that integrates profitability, environmental responsibility, and animal welfare. Such objectives may include soil conservation, manure nutrient utilization, the risk of nutrient loss, resulting yield and quality, the compatibility with existing feed storage facilities, the allocation of purchased and homegrown feeds across animal groups, the returns for each scenario, and the impact on whole farm mass nutrient balances. The linked decision aids would help consultants highlight bottlenecks or areas of high risk, explore root causes of problems, and determine plans for alleviating the constraints.

The linked system (outlined in Figure 2) recognizes that several key components remain to be developed or integrated by the CuNMPS (including an economic analysis tool, whole farm optimization model, and an overarching database for records and inputs/outputs common among decision support tools). The storage/record keeping component would be housed on farm and used regularly to record data from various farm enterprises. It will be a mix of commercially available software (e.g. Dairy Comp 305) and new software. The record keeping component must be able to output information to various process control centers on the farm (for example the outputted information could be generated automatically via scheduling by advisors utilizing decision aids, such as CNCPS and Cropware). While the record keeping component would be housed on-farm and used daily, the decision aids would primarily be utilized off-farm by advisors to generate recommendations based on farm performance. In order to ensure meaningful model evaluations, quality management research and protocols should continue to be paired with model use in order to know what to measure, model, and manage, how frequently to measure, model, and manage, and what range of performance represents a system working in proper control toward the farm goals.

Thus, we plan to design and add an input and output structure to the CuNMPS to transfer input and output data between the models (CNCPS, Cropware, Records, Economics, and Whole Farm Optimization) so that expected feed production with different crop rotations and management schemes can be more closely matched with herd nutrient requirements.

5. *Development of a whole farm optimization procedure*. An important tool to assist feed management is optimization (Tedeschi, 2001); therefore, the development

of a whole farm optimization will aid the better allocation and use of nutrients within a farm or in a basin.

We have developed a linear programming method to optimize ration formulation using the current CNCPS model structure (Tedeschi et al., 2000). Wang et al. (2000a; 2000b) developed and demonstrated an approach to whole farm optimization for nutrient and feed management. However, as discussed by Tedeschi (2001) complex whole-farm problems require nonlinear and(or) stochastic optimizations (Birge and Louveaux, 1997; Luenberger, 1984). Most farm management problems have an intrinsic dynamic nature, thus they can be solved through dynamic programming (Bertsekas, 1987; Kennedy, 1986); typical problems involving dynamic programming are crop, livestock, and land management (Kennedy, 1986). Multi-objective programming behavior is inherent in whole farm optimization and increases the model complexity (for example, one may want to minimize cost (or maximize profit) and decrease environmental pollution (excretion of N and/or P in the ecosystem) while optimizing land resource utilization) (Lara, 1993; Miettinen, 1999; Qureshi et al., 1999; Tozer and Stokes, 2001). The foremost goal of model optimization is the ability to provide producers, consultants, and researchers with tools to assist in complex problem solving and decision-making. Some efforts have been made to address the whole-farm optimization issue; we will continue exploring the operation research horizons to utilize the most up-to-date technology to improve our ability to optimize cost, nutrient, and land use at the farm and basin levels.

6. *Deployment of technology*. The goal is to develop and maintain websites to facilitate distribution and support for the CuNMPS, including guidelines (based on experience with use of the CuNMPS models on farms) that will reduce nutrients in manure.

We have a project with USDA-ARS scientists at Beltsville, MD in which we will jointly develop a website that utilizes the CuNMPS and their research data to provide tools and guidelines for reducing N and P losses from dairy farms.

7. *Implementation and Training*. Who is responsible for determining what data is required, collecting the data, analyzing the data, and modeling the whole farm in an integrated fashion is an issue we are beginning to address.

We recognize that crop consultants and nutritionists have severe time limitations due to current work demands and this level of integration adds many hours to each farm. It is easy to envision the crop systems to be modeled by crop consultants and rations (and some herd management) by nutritionists; however the added responsibilities of integrating and whole farm optimization are new domains. Potential vendors in this area are CNMP planners, SWCD and NRCS staff, and private consultants. Regardless of vendor, training in integration and systems thinking is required for agri-service and producers. We are beginning to develop training programs that will primarily train trainers (beginning with Extension staff).

## ON FARM RESEARCH TO IMPROVE THE CuNMPS

Development and refinement of the CuNMPS will be enhanced through field based research. Such research has proven valuable in enhancing practical application of the models and increasing rate of adoption of this technology in the field. The recent precision feeding project in Delaware County is an example of how use and development of the CuNMPS can be part of a TMDL driven comprehensive watershed management program (Cerosaletti et al., 2002; DCAP II, 2002). In this project the CNCPS v. 4.0 was used on dairy farms in the Cannonsville Reservoir Basin (part of the New York City drinking water supply) resulting in reductions of feed phosphorus imports 25 to 30% and manure phosphorus excretions 33%. Project specialists provided feedback to the CNCPS development team on version 4.0, and CNCPS training for the local feed industry was conducted. Future field research plans in Delaware County and the Cannonsville watershed include use of the CNCPS model in a larger scale implementation of precision feeding as well as further efforts to integrate modeling and planning of field crop and feeding systems to achieve greater nutrient import reductions on farms. Nutrient source reductions will be a major emphasis in the Cannonsville basin, which is under a TMDL. Investigating linking of CuNMPS software with other software tools will be part of this effort. The Delaware County Action Plan for Watershed Protection and Economic Vitality (DCAP II, 2002) identifies the development of the CuNMPS as critical scientific support for comprehensive water quality efforts in farm nutrient management in Delaware County.

The application of the CuNMPS on farms will require on-going education and resources for systems level thinking and quality management for all participants, including farm managers across a diversity of farms, advisors, researchers and CuNMPS developers. Assembling an initial farm advisory team, defining the farm missions and goals, charting the basic systems on the farm, and characterizing the baseline performance of the farm through various assessments tools (including the CuNMPS) will position the farm for progressive (and sometimes radical) change. Based on the initial inventory, the CuNMPS will be a key tool for determining the best combination of alternatives across farm systems. Outlining plans for more compatible cropping, feed storage, feeding, herd, and manure systems with the assistance of the CuNMPS has the potential to help farm managers develop more sustainable dairy farm systems in a business context where efficiency is favored in order to satisfy market, societal, and environmental pressures. Implementing and improving the plan will require the development of quality management schemes throughout the farm and beyond, including service and product vendors. The CuNMPS will play an important role in the quality management of the farm, because it will supply valuable information to help the management team to apply the DMAIC principle to the farm (Define, Measure, Analyze, Improve, and Control) (Pande et al., 2000) to ensure efficient implementation and improvement of plans over time. Record keeping and analysis is implicit in quality management, so documentation of improvements in profitability and nutrient flows will be natural products of the efforts. Applying and documenting this approach with management teams on a diversity of case study farms will provide the experience and data necessary to organize and articulate the approach to broader audiences and motivate such audiences to adopt similar strategies for more sustainable dairy farm systems.

## CONCLUSIONS

Dairy and beef operations in New York and the United States have been evolving for many decades primarily driven by economic sustainability. Margins have been highly variable in recent years and we are continuing to see society force these industries to change to become environmentally sustainable. This combination has led most producers to a difficult three-way intersection: (1) comply with environmental regulations and potentially erode margins further, (2) ignore regulations and conduct business as usual, or (3) begin to re-engineer the farm's management and systems requiring radical changes resulting in environmental and economic sustainability. Those that select options one or two place the future of their businesses in grave danger as society, and economics, will continue to demand improvements. It is our desire that most farms select option three as it is what we consider to be the best option to ensure a safe, high quality, and affordable food supply while protecting our soil and water resources and providing for the quality of life desired by the producers. We plan to continue assisting the involved industries to provide tools (CuNMPS), research, support, and training so that the goals of agri-service, production agriculture, and society can be met.

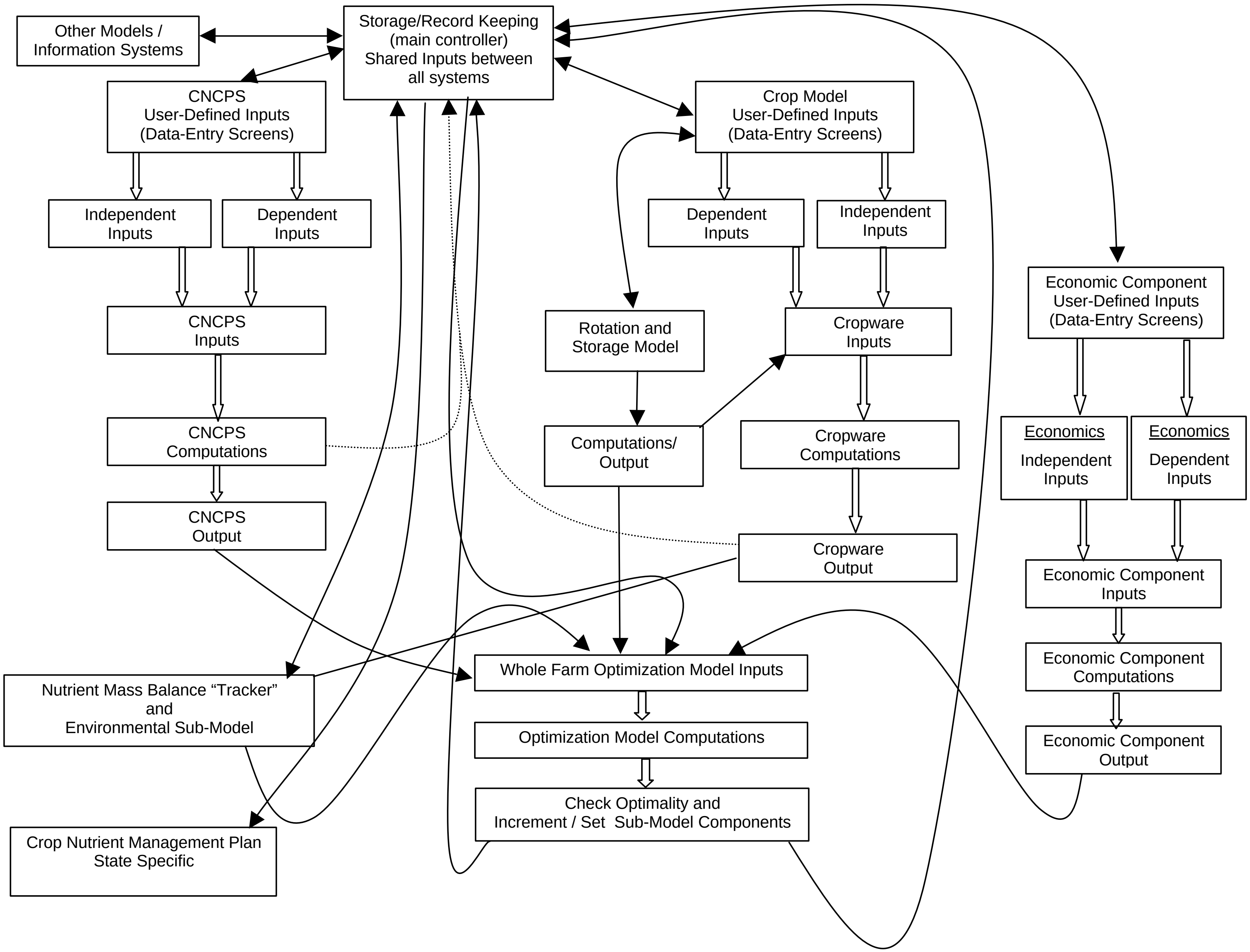


Figure 2. A flowchart of the linked CuNMPS systems

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